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EVALUATION OF PLZT GOGGLES

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NOTICES

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Air Force Prototype Thermal Flash Protective Device (TFPD) Goggles, No. R04053.00, BBN.X.244.H77, and Production-type TFPD Goggles, No. R04053 79C00170, were furnished to USAFSAM by the Life Support System Program Office, Aeronautical Systems Division, for determination and evaluation of their eye-protection capabilities. The bonding used to assemble the lens in the prototype goggles caused stressed areas. The bonding used in the production model eliminated the stressed areas, resulting in increased closed-state optical density, particularly in the upper nasal area of the lens.

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20. ABSTRACT (Continued)

The spectral density of the goggles and the percent of change of the density as a function of time are shown for three different angular conditions of looking through the goggles. Predicted eye effects (retinal burns and flashblindness) are listed for detonation yields from 0.1 to 10,000 kt, with the observer at distances where the thermal load on the goggles is 10 cal/cm^2. The predicted eye effects indicate that the production model TFPD provides more eye protection than does the prototype model. The production model goggles will prevent retinal burns from nuclear detonations under all exposure conditions tested and reduce daytime flashblindness recovery time to 3 sec or less. At night, however, the predicted flashblindness recovery time can be 16-18 sec for the lower-yield detonations (10 kt or less), even if the observer blinks. If a nuclear flash were encountered at night, an immediate increase in instrument luminance to between 7 ml and 100 ml could significantly reduce the time that the pilot was unable to see his instruments.

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EVALUATION OF PLZT GOGGLES

INTRODUCTION

The Air Force, concerned for many years about the impact that viewing a nuclear flash without adequate protection would have on mission performance, has expended much time and money in an effort to develop an effective eye-protection device for use by aircrew members. The latest result of this development effort is the PLZT (lanthanum-modified lead zirconate titanate) Thermal Flash Protective Device (TFPD). Stated simply, this device consists of crossed polarizers with a thin sheet of PLZT between them. The device is transparent when an appropriate voltage is applied to the PLZT but is opaque when the voltage is removed. A small power supply furnishes the necessary voltage, and a phototransistor detects the light from a nuclear flash (or other source of high-intensity light) and controls the circuit that applies this voltage to the PLZT.

A prototype TFPD, number R04053 BBN.X.244.H77, was furnished to the USAF School of Aerospace Medicine (USAFSAM) by the Life Support System Program Office, Aeronautical Systems Division (ASD/AELS), with a request that the eye-protection capabilities of the device be determined and evaluated. The technique used to bond the various layers of the lens assembly in this prototype causes stressed areas in the final assembly (1)--resulting generally in a reduction of the closed-state optical density throughout the lens assembly, and resulting particularly in a significant reduction in the closed-state density in these stressed areas for large angles of incidence of the entering light.

The objective of this study was to determine and evaluate the amount of eye protection provided by the prototype goggles with these stressed areas.

Before that study was completed, however, the lens-bonding technique was changed and the stressed areas eliminated. The new bonding technique used in production models of the PLZT goggles resulted in an improved closed-state density. ASD/AELS provided a production-type TFPD, number R04053 79C00170 (officially designated as Goggles, Flyers, Flashblindness EEN-2/p and stock-listed under #8475-01-017-4473), to USAFSAM and requested that the protection capabilities of these goggles also be determined and evaluated. The objective of this study, therefore, was so expanded.

PROCEDURES

To calculate the severity of a retinal burn or duration of flashblindness associated with viewing a nuclear flash while using an eye-protection device, we must know, among other things, the spectral transmission of that device as a function of time (2). This information was not known for the two devices provided, so a series of measurements were needed before we could determine their protective capabilities. The procedures used to determine the spectral transmission as a function of time for the two devices were slightly different and will be described separately.

Prototype TFPD

The transmission of crossed polarizers, and consequently the closed state of the protective devices, is a function of the angle at which the incident light strikes the surface. Thus, we had to measure the spectral transmission for different angular conditions.

For a prototype PLZT sample lens, a Beckman ACTA MVII spectrophotometer was used to measure the optical density as a function of wavelength in the spectral region from 350 to 1400 nm. (These measurements could not be made on the goggles because the sample chamber of the spectrophotometer was too small to accommodate them. Also, the goggles could not be held in the partially open state as could the sample lens.) The optical density was measured for the open state, the closed state, and four conditions of partial closure for each of three angular conditions ($\theta_i = \theta_\rho = 0$; $\theta_i = 18°$, $\theta_\rho = 0$; and $\theta_i = 37°$, $\theta_\rho = 43°$). The angle θ_i lies between the incident light ray and a normal to the surface, and θ_ρ is the angle between the incident light projected to the surface and the polarizer axis that results in the smallest θ_ρ (Fig. 1).

The angular condition $\theta_i = 18°$, $\theta_\rho = 0$ corresponds to looking straight ahead through the goggles and is considered the normal condition. The condition $\theta_i = 37°$, $\theta_\rho = 43°$ corresponds to looking to the upper left or upper right, through the point that maximized θ_ρ, a "worst case" situation. This condition is true for the left eye only when looking to the upper right, and for the right eye only when looking to the upper left; in either case, the other eye is looking through the upper central portion of the lens, with the condition $\theta_i = 18°$, $\theta_\rho = 0$.

The optical density for these various conditions is shown as a function of wavelength in Figures 2-4. These figures show that the relative change in optical density, as expected from theory (1), is essentially independent of wavelength as the PLZT lens opens or closes for the three angular conditions shown.

Using lasers operating at 482, 568, and 632.8 nm, the optical density of the goggles was measured in the fully open and fully closed states for each of the three angular positions described. In addition, the change in optical density as a function of time during the closing cycle and during the servo-controlled opening cycle was measured for each of the three wavelengths and angular positions.

The measured optical density of the goggles for each of the test conditions was used with the relative spectral density of the sample lens to determine the open- and closed-state optical density of the goggles as a function of wavelength for the three angular conditions tested. The results (Figs. 5-7) were used to obtain the density of the goggles in the open and closed state for each of the three angular conditions tested, for each spectral band used in the computer program (2).

A 5th-order polynomial expansion was calculated, using a least-squares fit, to describe the percent change in optical density as a function of time for the opening and closing cycles for each of the three angular positions.

We found that the percent change for the angular positions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$ could be described with the same polynomial, as expected from theory (1). Figures 8 and 9 show curves used for the closing cycle; Figures 10 and 11, the opening cycle. The closing cycle of the goggles was not initiated by a light flash but by a signal applied directly to the trigger circuit through leads inserted by Bendix Corporation. Thus the 7.9×10^{-6} second before the goggles start to close is a delay in the PLZT and associated electronic circuitry after a trigger signal has been received. The delay time of 1 second before the opening cycle starts was not present in the prototype goggle tested but has been incorporated in newer models (1). This delay has, therefore, been included here and in the computer program that calculates the spectral transmission of the goggles as a function of time. One surprising feature is that the time required to reach the fully closed state (2.2×10^{-4} sec) for $\theta_i = 37°$, $\theta_\rho = 43°$ is only about 1/3 the time (6×10^{-4} sec) required in the other angular conditions. These times were expected to be approximately equal (1).

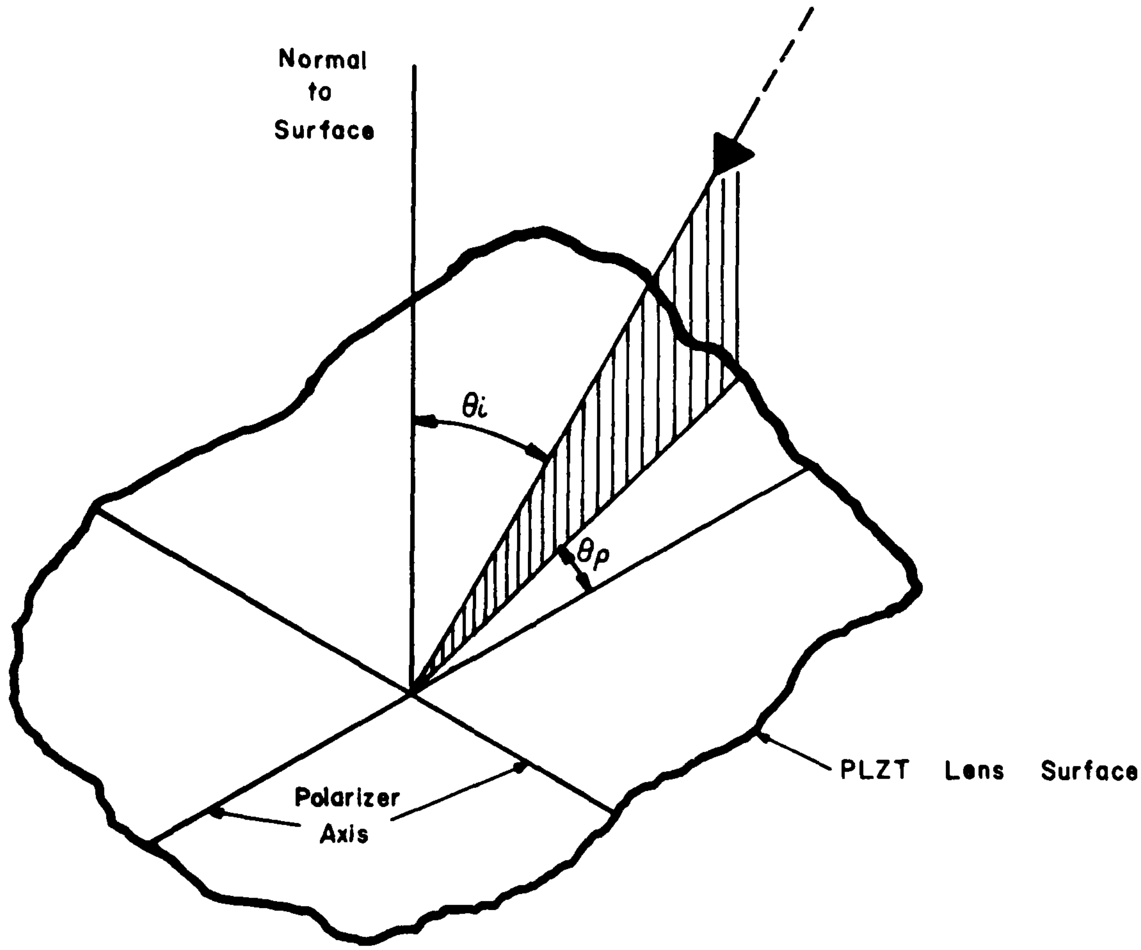

Figure 1. Angle of incidence, θ_i, is the angle between the incident light ray and a normal to the lens surface. Angle of polarization, θ_ρ, is the angle between the projection of the light ray to the lens surface and the polarizer axis that results in the smaller value of θ_ρ.

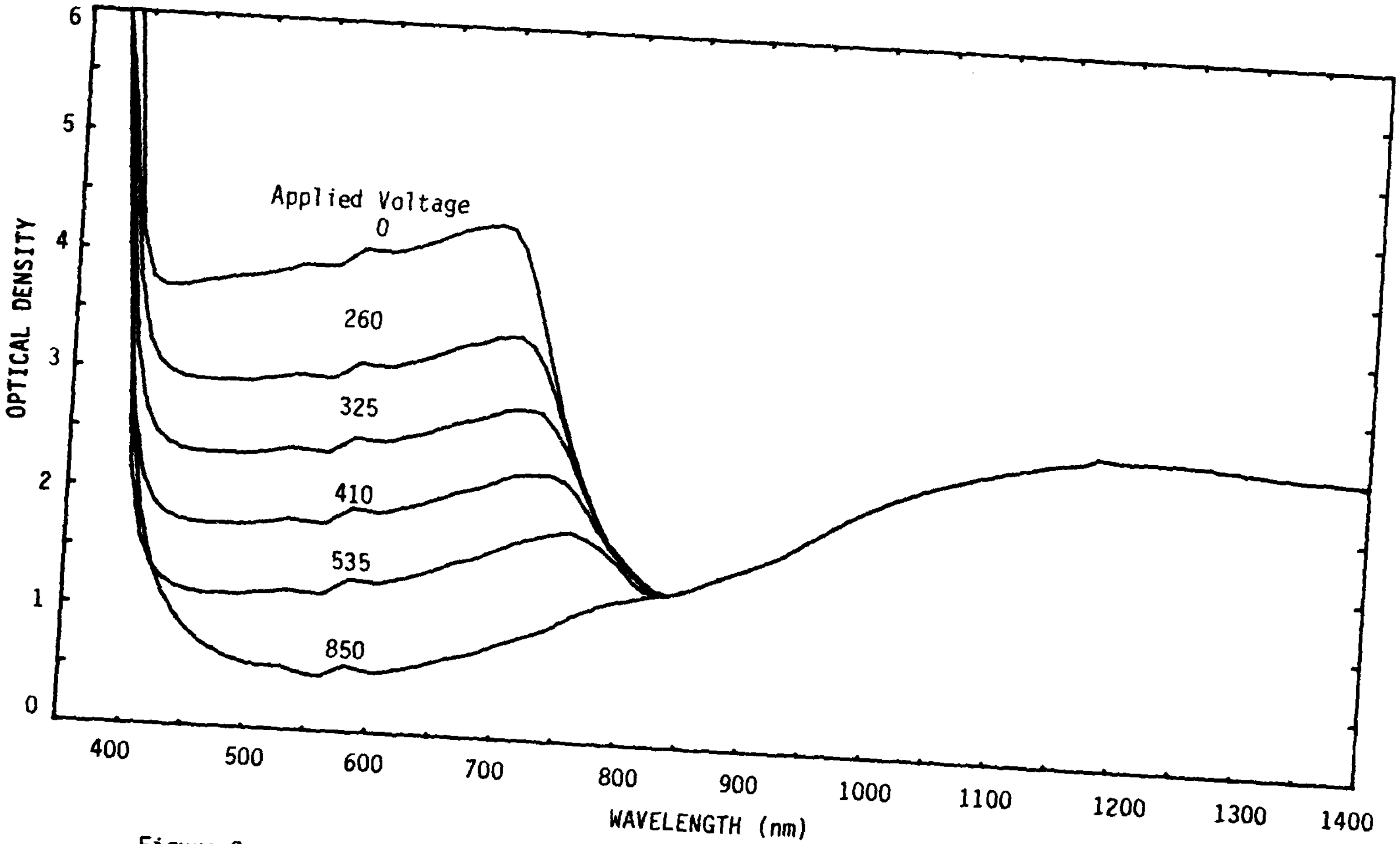

Figure 2. Spectral density of PLZT prototype sample lens for condition $\theta_i = \theta_\rho = 0$.

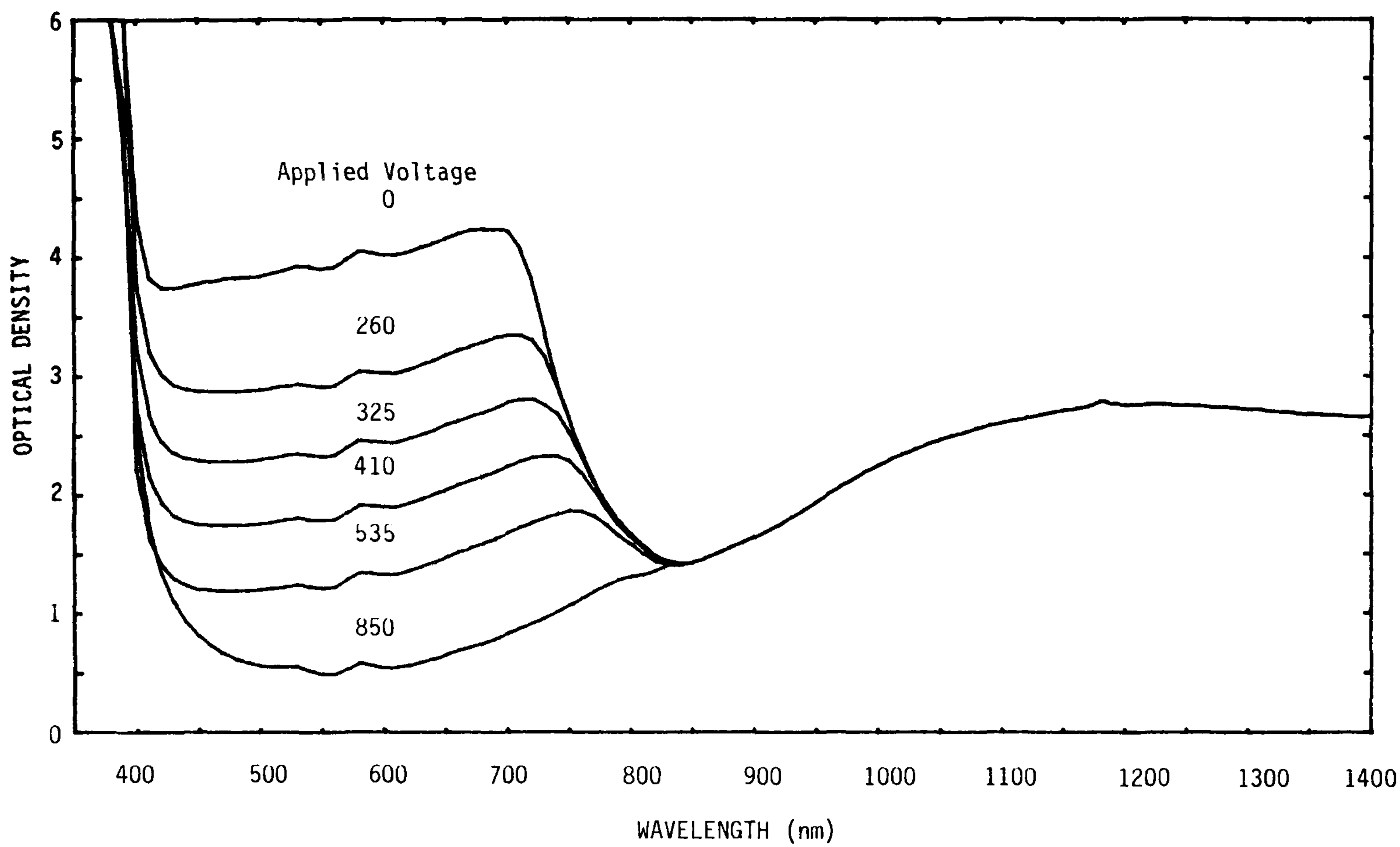

Figure 3. Spectral density of PLZT prototype sample lens for condition $\theta_i = 18°$, $\theta_\rho = 0$.

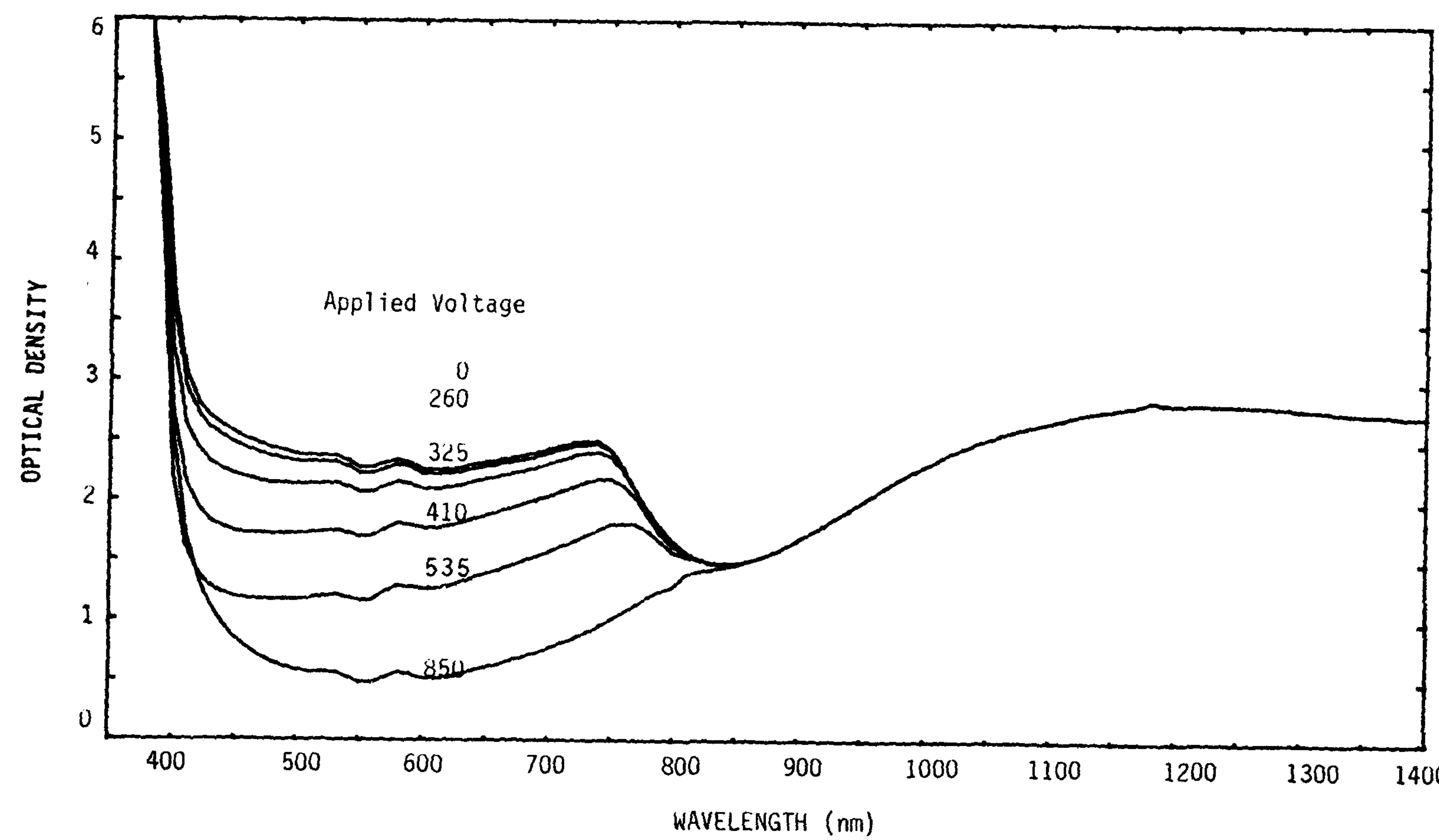

Figure 4. Spectral density of PLZT prototype sample lens for condition $\theta_i = 37°$, $\theta_\rho = 43°$.

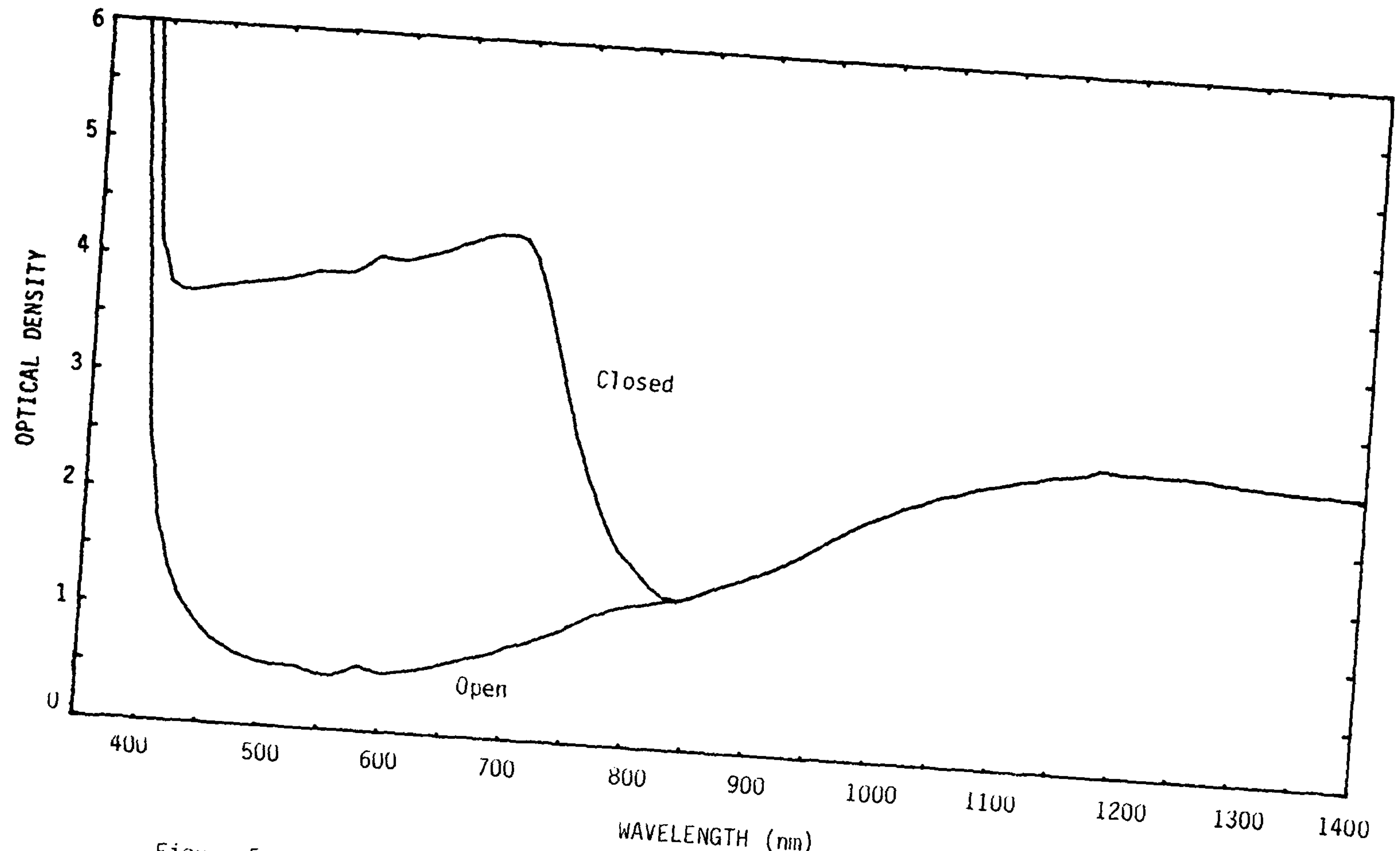

Figure 5. Spectral density of PLZT prototype goggles for condition $\theta_i = \theta_\rho = 0$.

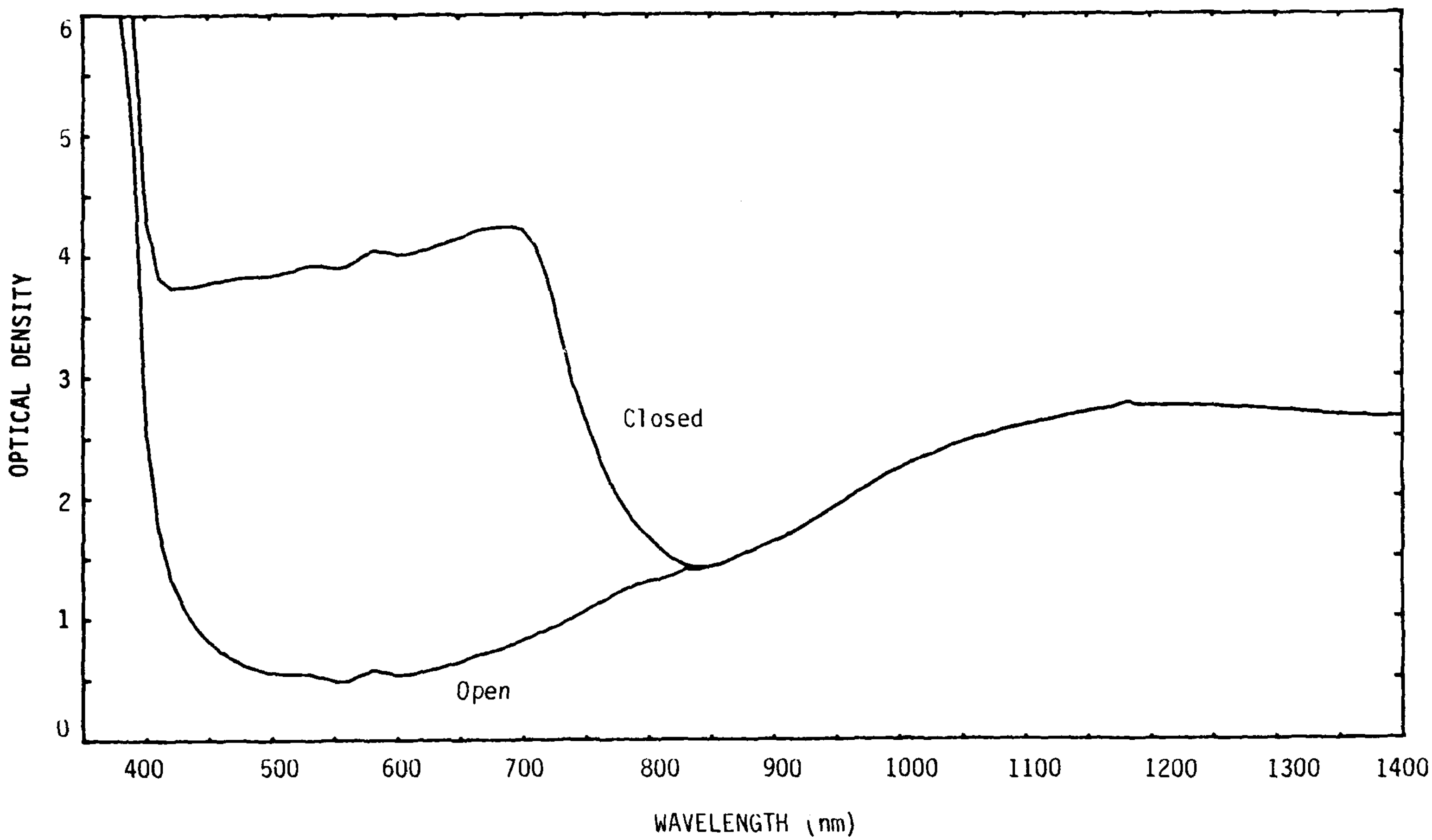

Figure 6. Spectral density of PLZT prototype goggles for condition $\theta_i = 18°$, $\theta_\rho = 0$.

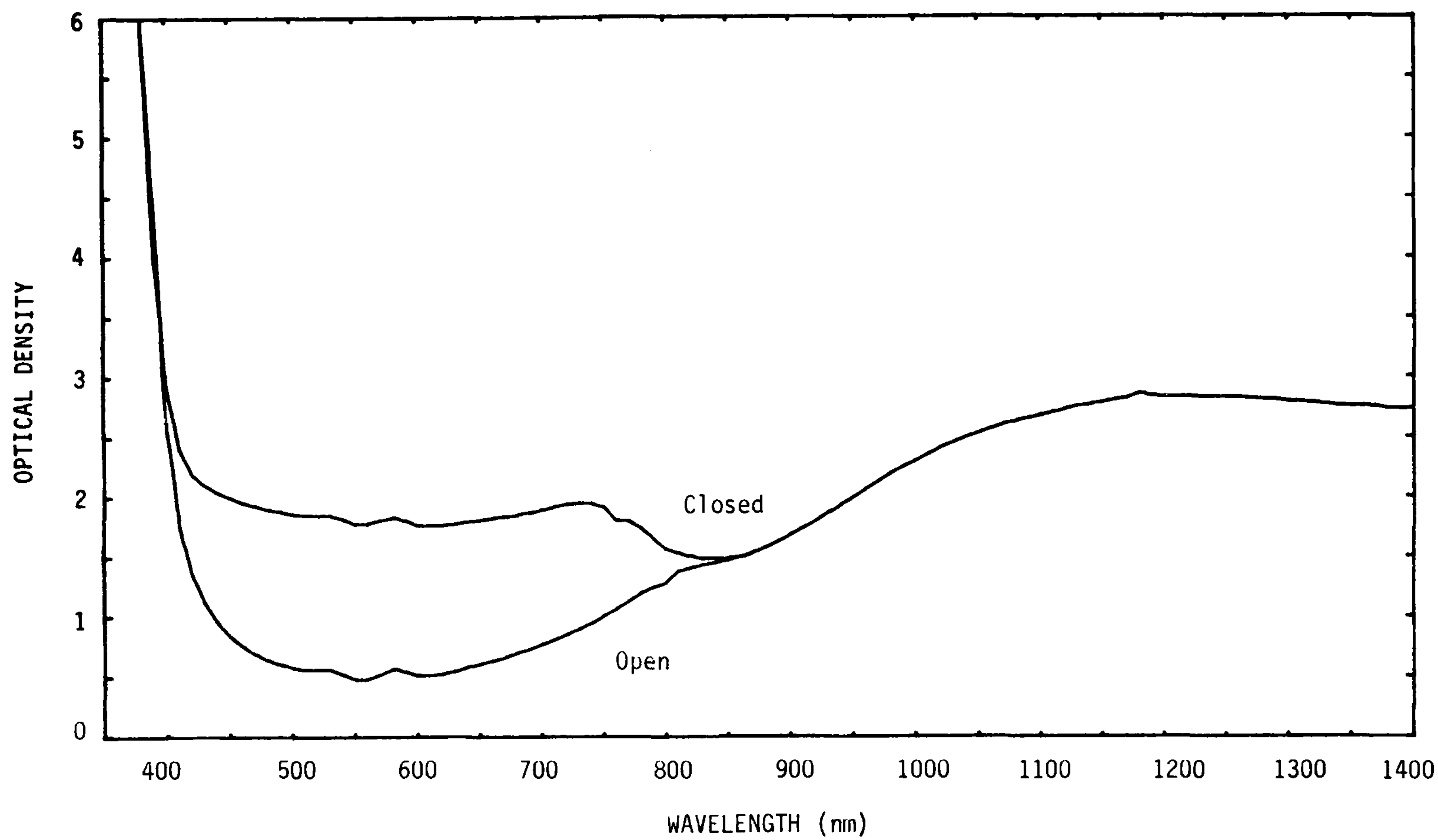

Figure 7. Spectral density of PLZT prototype goggles for condition $\theta_i = 37°$, $\theta_\rho = 43°$.

Production-type TFPD

A Beckman ACTA MVII spectrophotometer was used to measure the optical density of two PLZT production-type sample lenses as a function of wavelength in the spectral region from 350 to 1400 nm. The optical density was measured for the open and closed states for each of the three angular conditions discussed previously. Since previous measurements (Figs. 2-4) had shown that the relative change in optical density was independent of wavelength as the PLZT lens opened or closed, the measurements for the partially closed conditions were not repeated. The spectral density for the $\theta_i = \theta_\rho = 0$ position was measured both after a minimum of 12 hours in the closed state and after 4 hours in the open state, to test for possible "space charge" effects.

Using a HeNe laser operating at 632.8 nm, the optical density of the goggles in the open and closed states and the change in optical density as a function of time during the closing cycle and during the servo-controlled opening cycles were measured for each of the three angular positions.

The spectral densities measured after a minimum of 12 hours in the closed state and 4 hours in the open state were within ± 1.5%, indicating that no measurable change in density occurred after 4 hours of continuous open-state operation. The spectral densities of the two sample lenses were within ± 1.5% when compared for similar conditions. In addition, at 632.8 nm, they were within ± 1% of the goggle density for the same conditions. Consequently, the spectral densities of the two sample lenses were averaged (Figs. 12-14) and considered representative of the spectral densities of production-type TFPDs.

A 5th-order polynomial expansion, as described for the prototype goggles, was calculated to describe the percent change in optical density as a function of time. Again we found that the percent change for angular positions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$ could be described with the same polynomial. Figures 15 and 16 show curves used for the closing cycle; Figures 17 and 18, the opening cycle. The 7×10^{-6}-second delay before the goggles start to close is inherent in the PLZT and associated electronic circuitry, and the 1.5-second delay before the goggles start to open is a measured characteristic of the TFPD tested. We see that, as with the prototype TFPD, the time required to reach the fully closed state (1×10^{-4} sec) for $\theta_i = 37°$, $\theta_\rho = 43°$ is only about 1/3 the time (2.8×10^{-4} sec) required in the other angular conditions. Also we see that the time required by the production-type goggle to reach the fully closed state is only 1/2 that required by the prototype goggles under the same conditions.

An existing computer program to predict eye safe separation distances from nuclear flashes (2) was modified to predict the distance from a nuclear flash at which a 10 cal/cm^2 thermal load will occur. The modified program was then used to predict the distance for this thermal load for six different detonation yield and altitude combinations: 0.1, 1, and 10 kt at 1,000 ft (0.3 km); 100 and 1000 kt at 5,000 ft (1.5 km); and 10,000 kt at 10,000 ft (3.0 km); for two visibilities, 5 and 25 nautical miles (9.3 and 46.3 km), and two observer altitudes, sea level and detonation altitude.

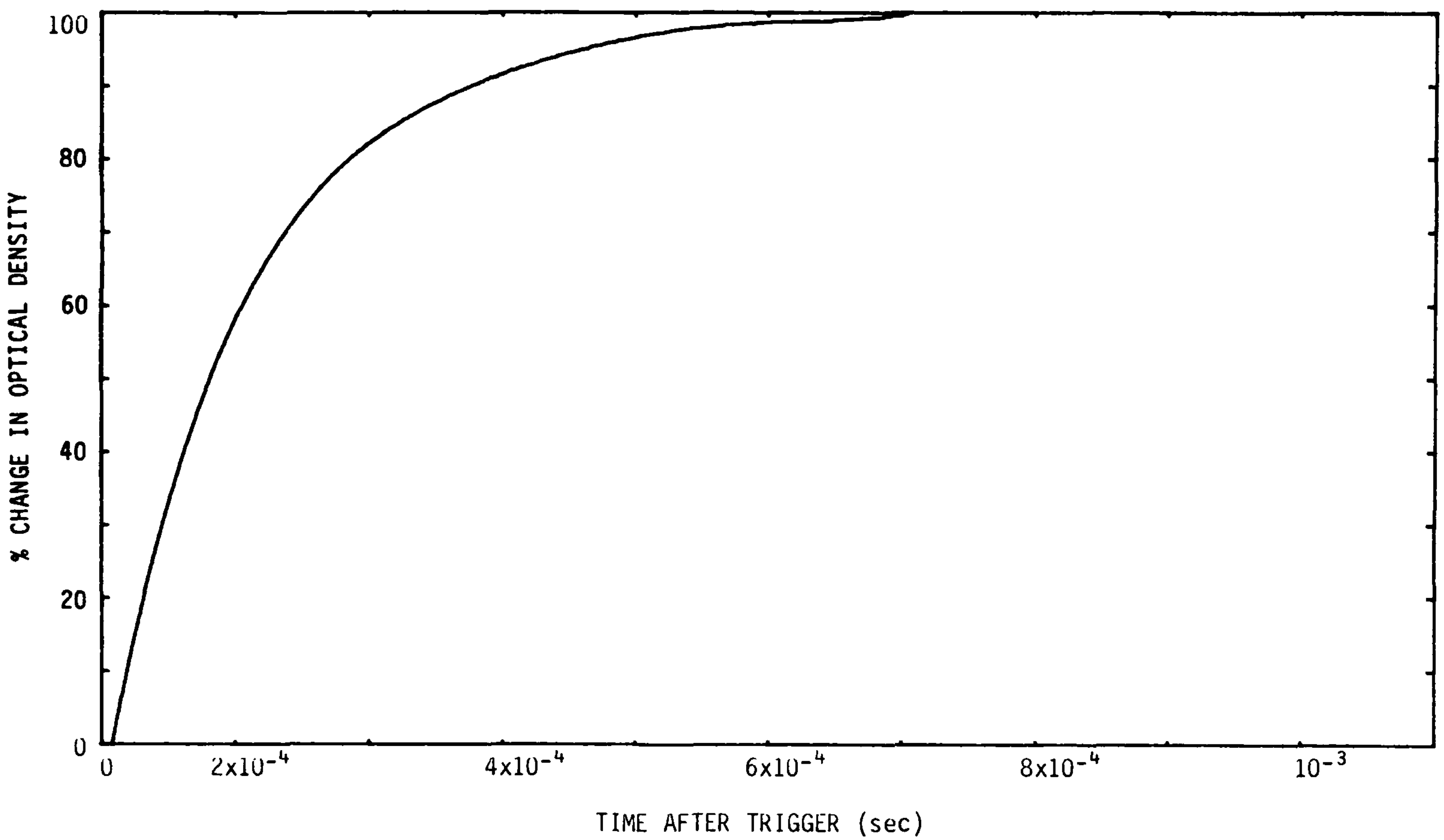

Figure 8. Percent of change in optical density as a function of time after activation for PLZT prototype goggles in the closing cycle for conditions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$.

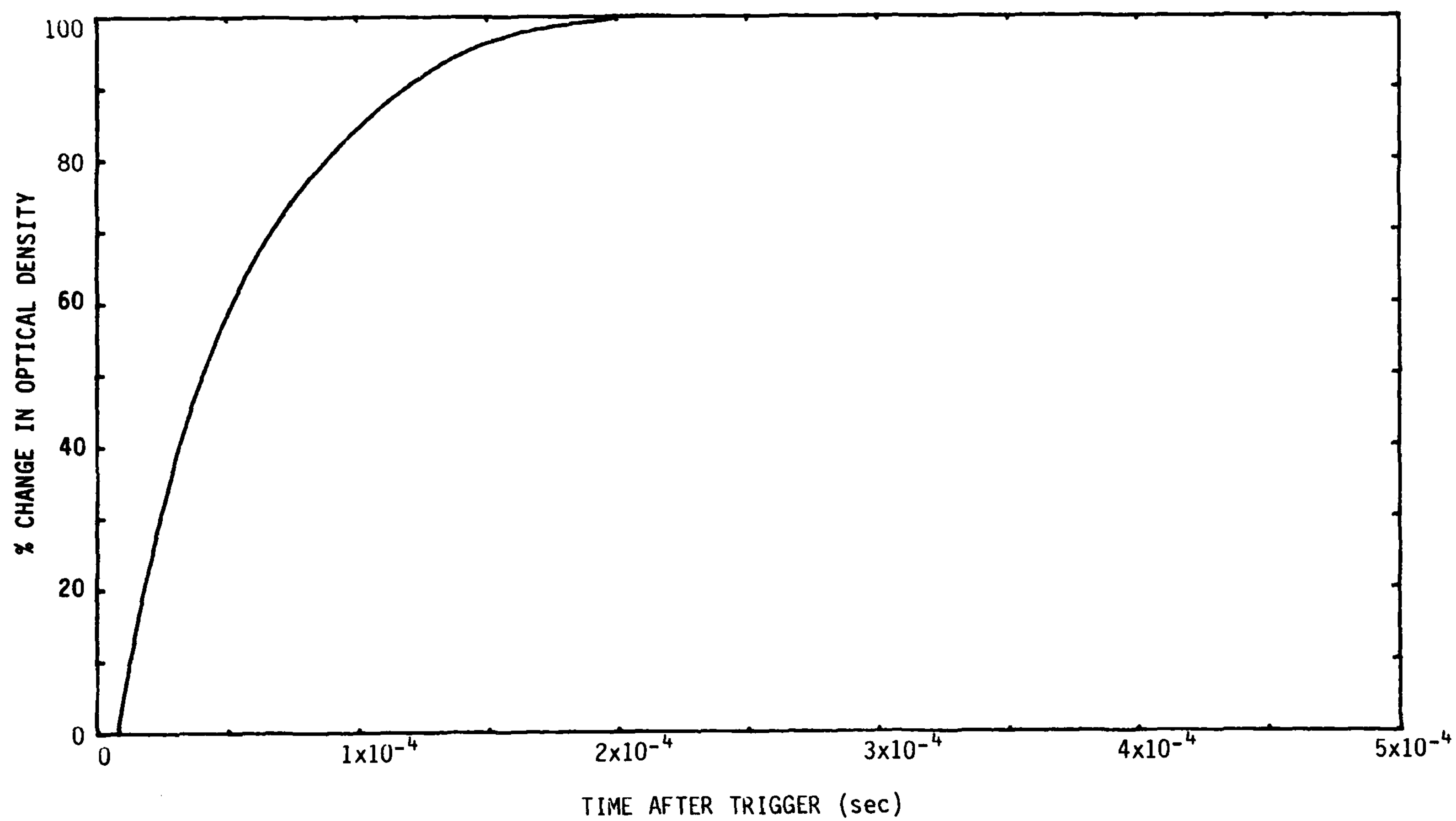

Figure 9. Percent of change in optical density as a function of time after activation for PLZT prototype goggles in the closing cycle for the $\theta_i = 37°$, $\theta_p = 43°$.

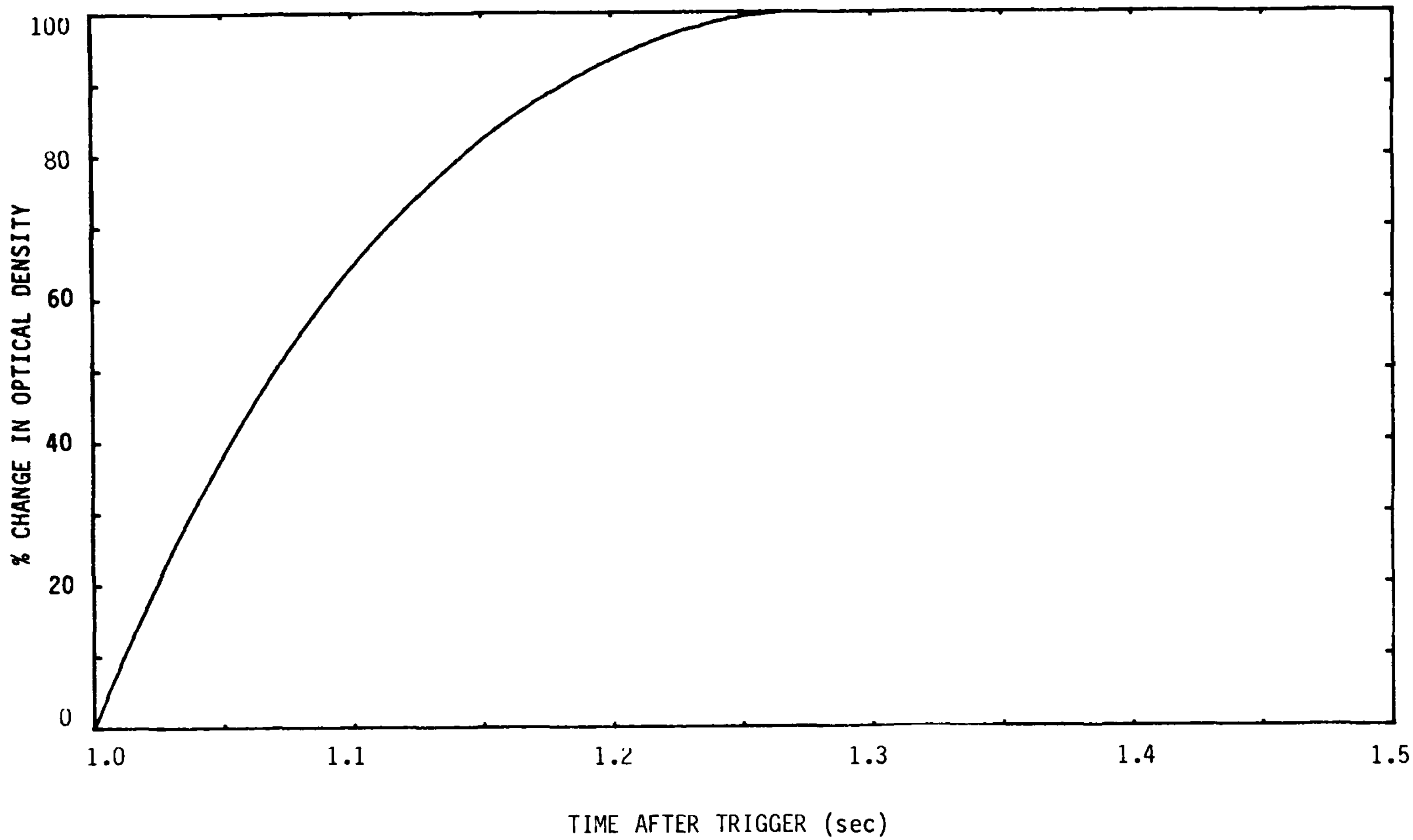

Figure 10. Percent of change in optical density as a function of time after activation for PLZT prototype goggles in the opening cycle for conditions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$ (assumes no change in ambient light).

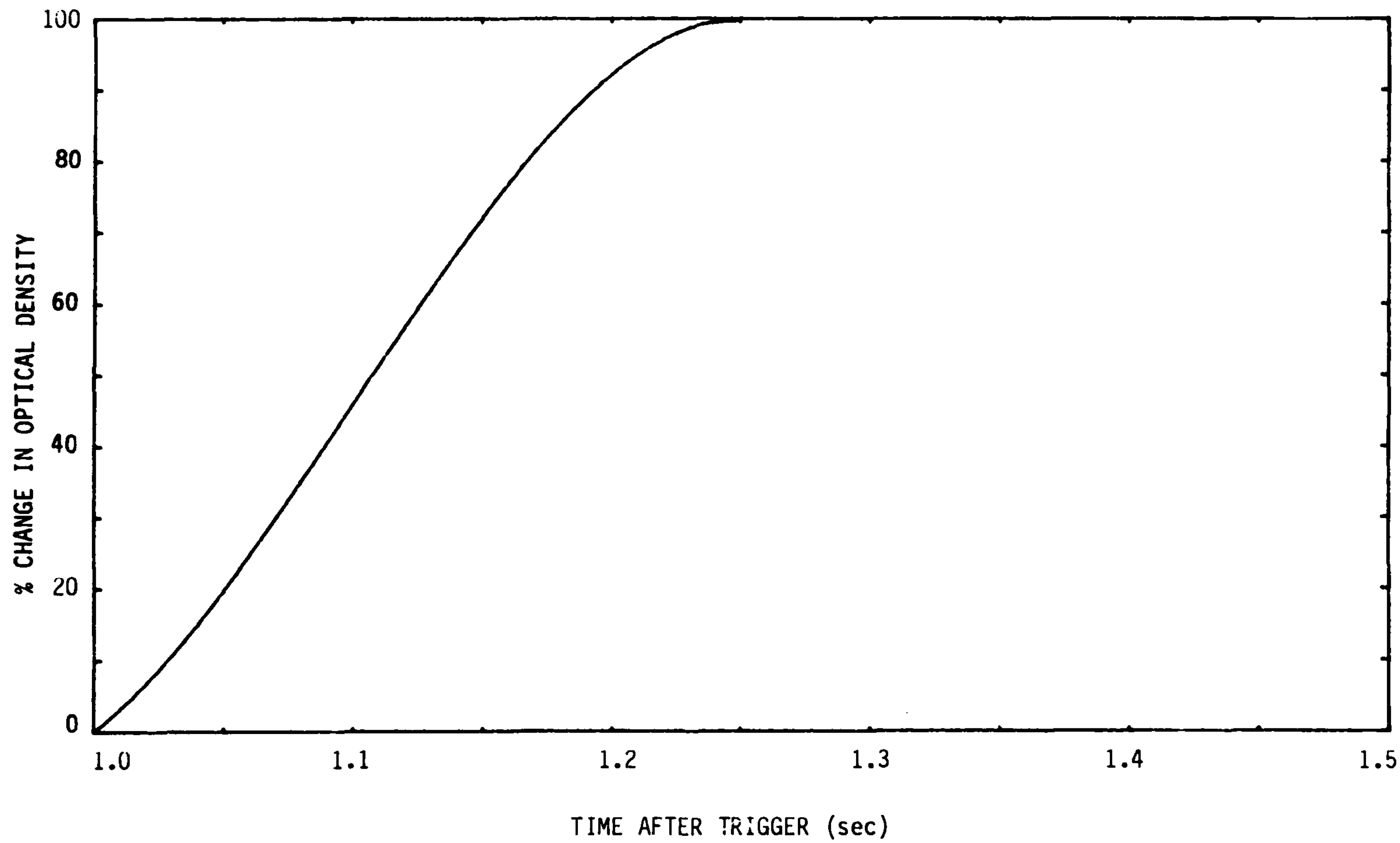

Figure 11. Percent of change in optical density as a function of time after activation for PLZT prototype goggles in the opening cycle for condition $\theta_i = 37°$, $\theta_\rho = 43°$ (assumes no change in ambient light).

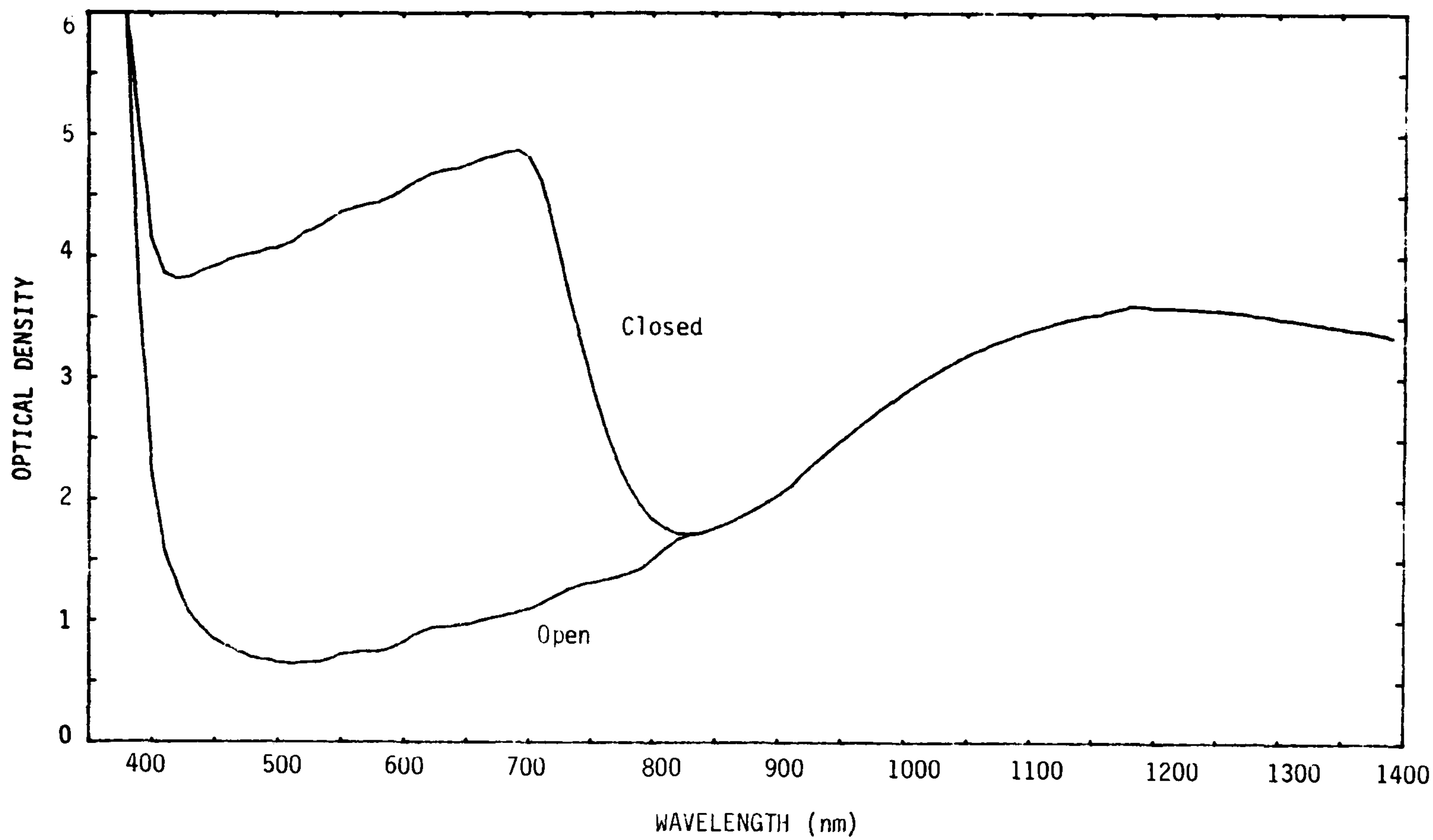

Figure 12. Spectral density of PLZT production goggles for condition $\theta_i = \theta_\rho = 0$.

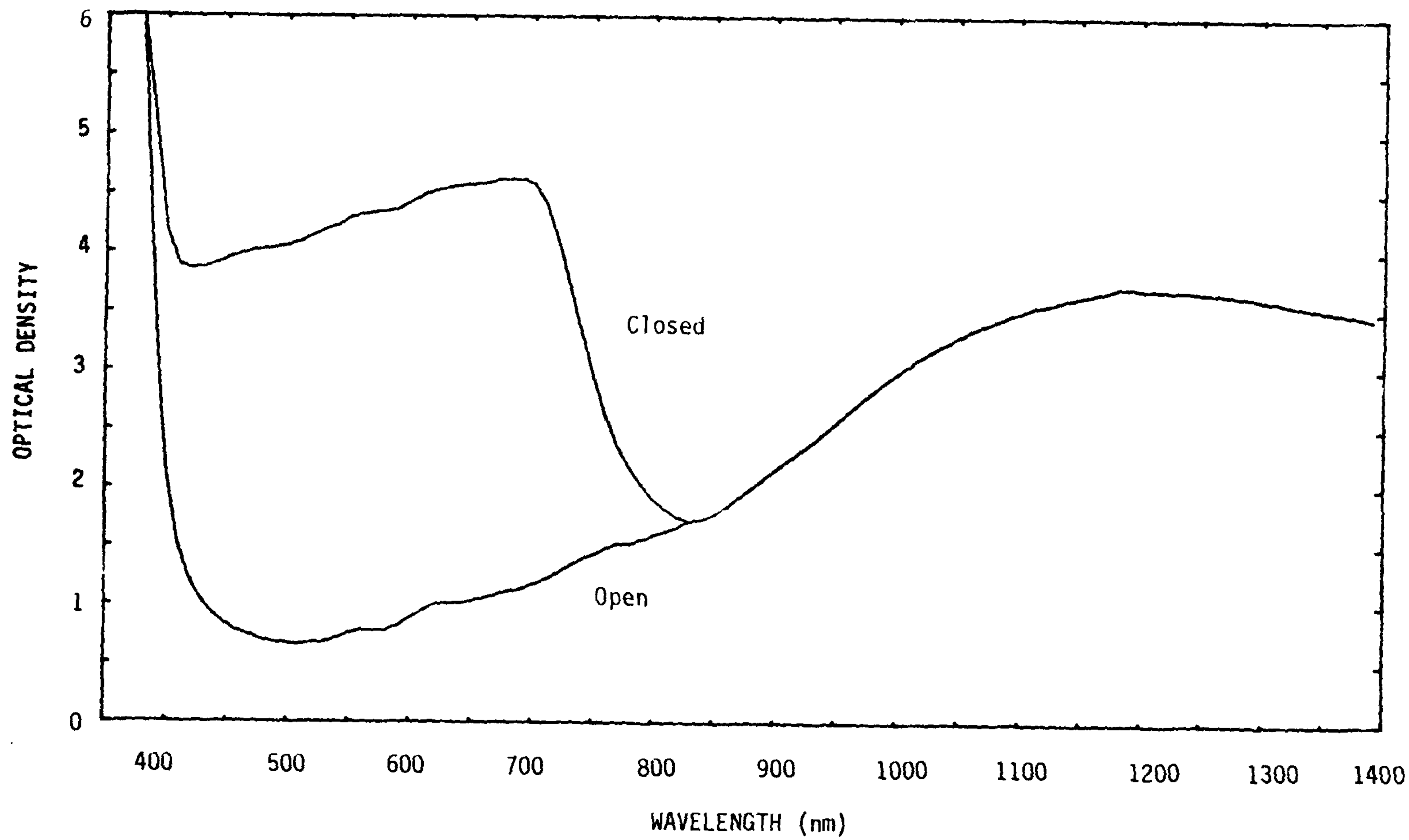

Figure 13. Spectral density of PLZT production goggles for condition $\theta_i = 18°$, $\theta_\rho = 0$.

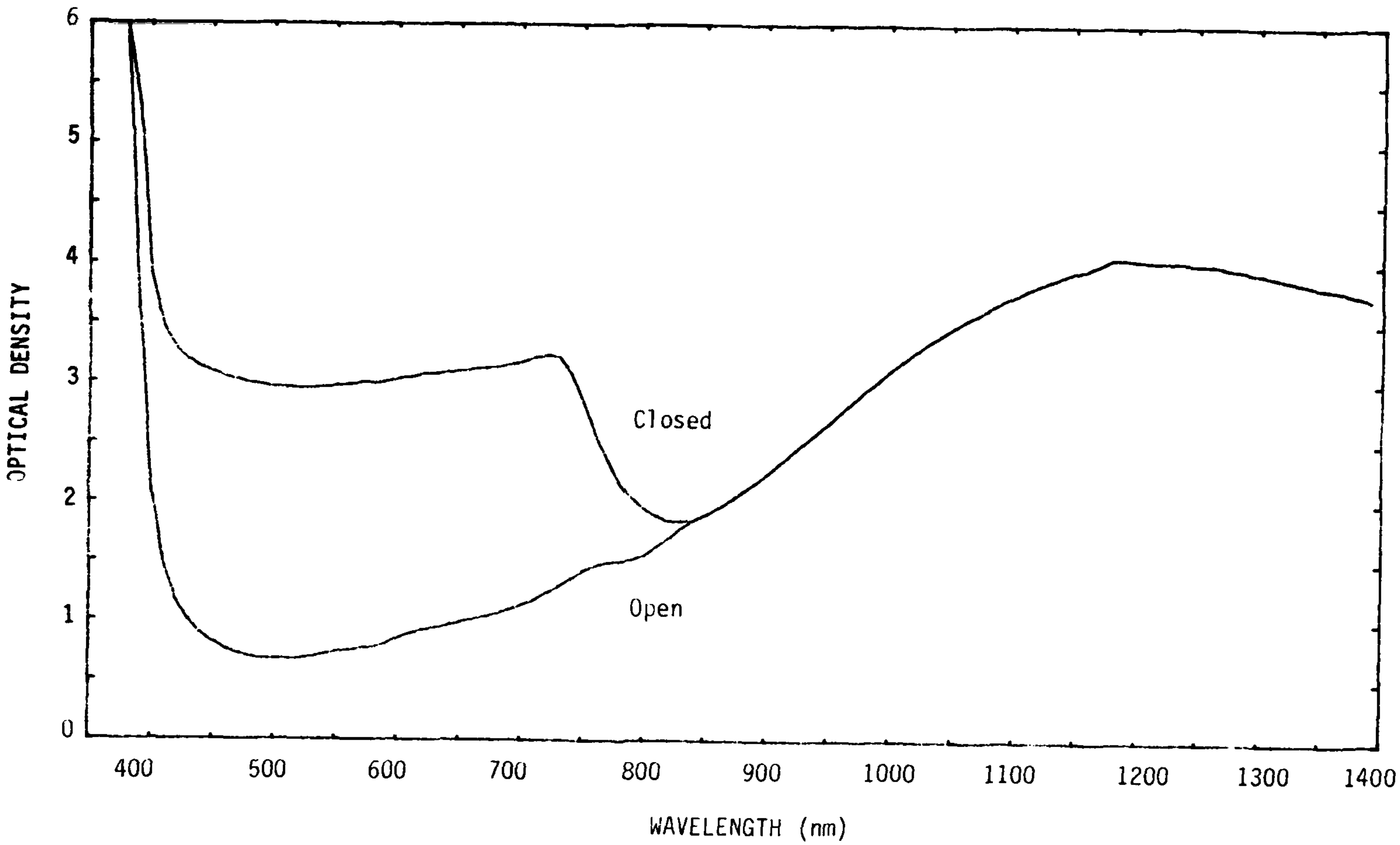

Figure 14. Spectral density of PLZT production goggles for condition $\theta_i = 37°$, $\theta_\rho = 43°$.

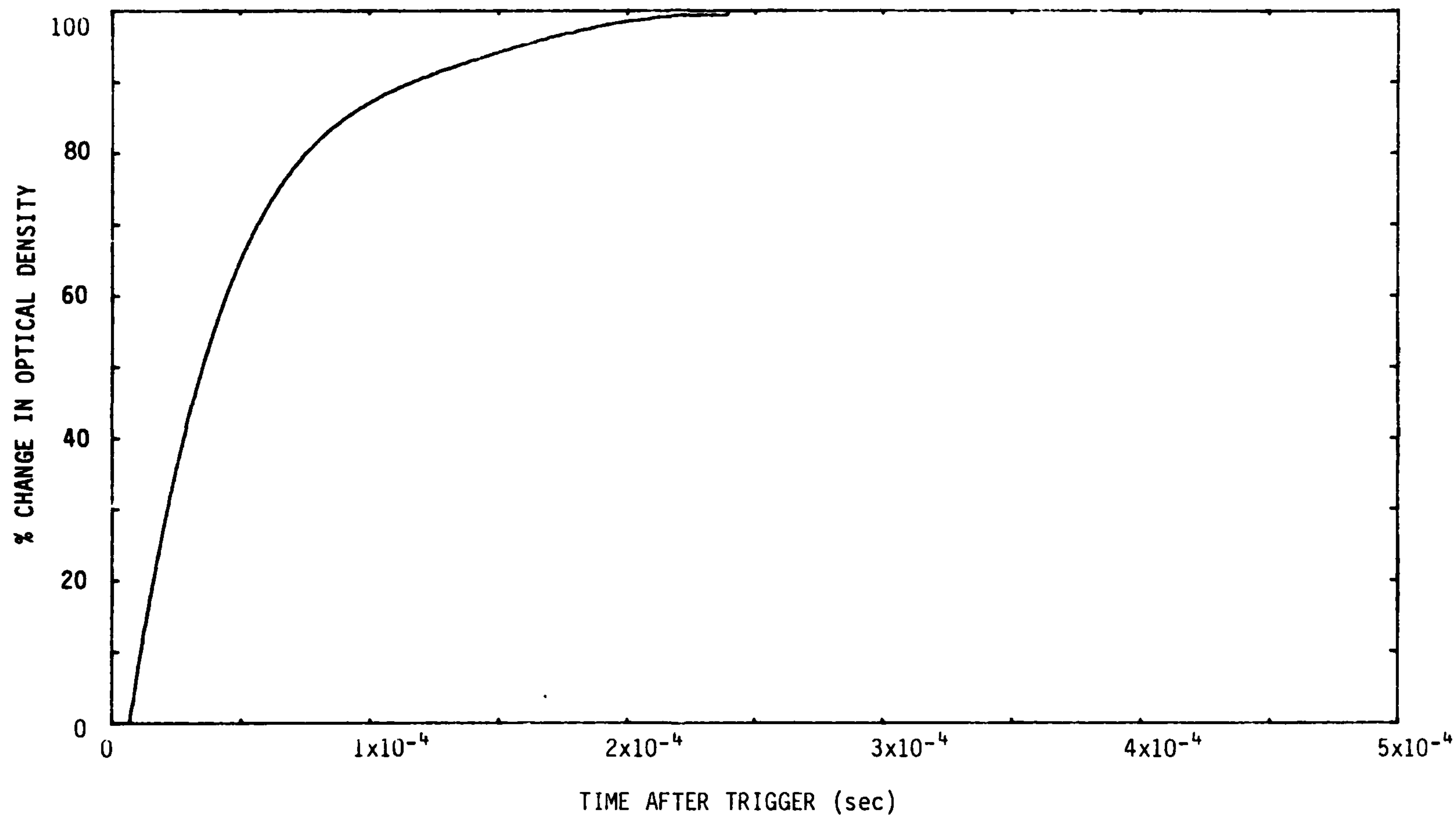

Figure 15. Percent of change in optical density as a function of time after activation for PLZT production goggles in the closing cycle for conditions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$.

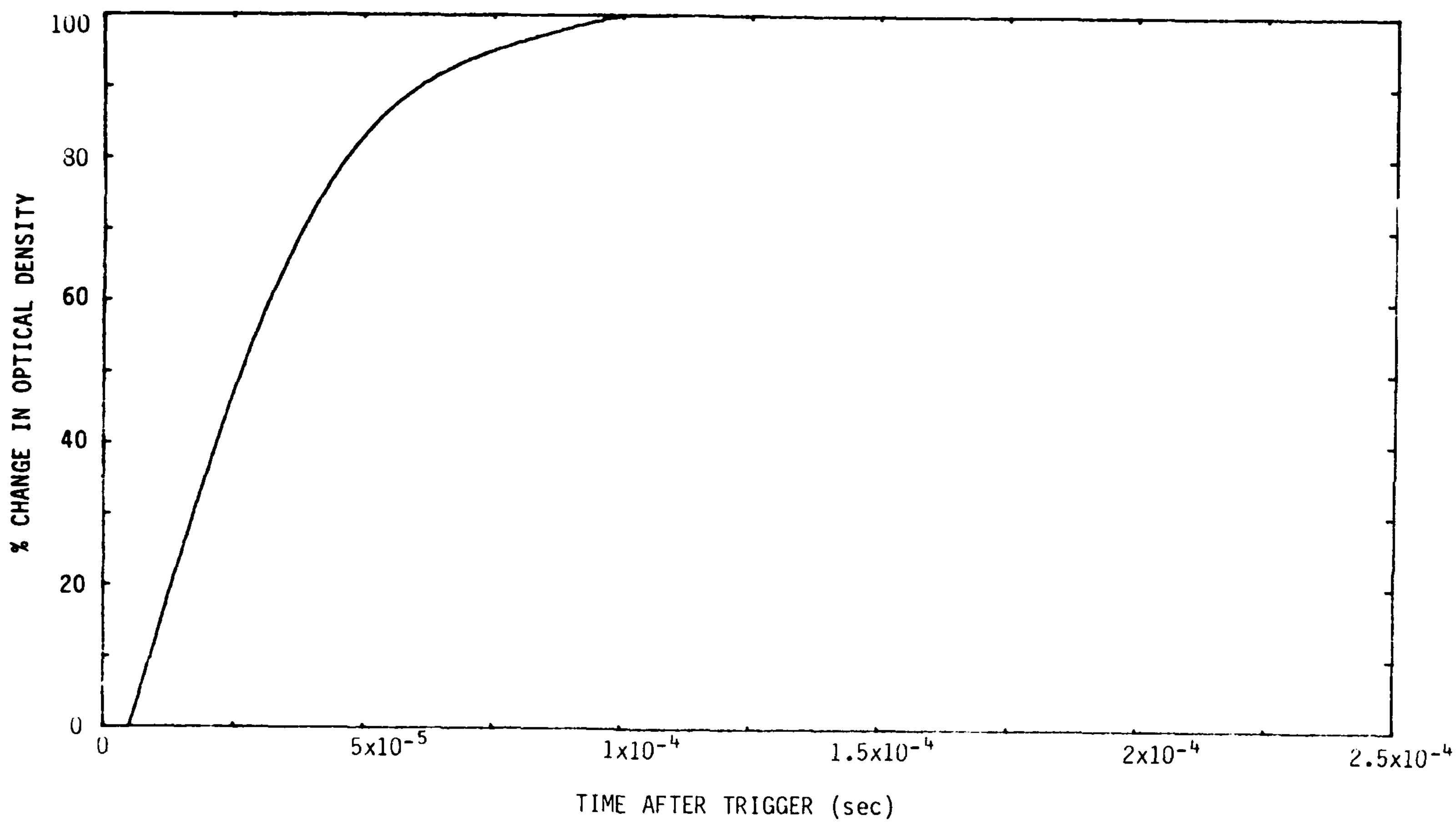

Figure 16. Percent of change in optical density as a function of time after activation for PLZT production goggles in the closing cycle for condition $\theta_i = 37°$, $\theta_\rho = 43°$.

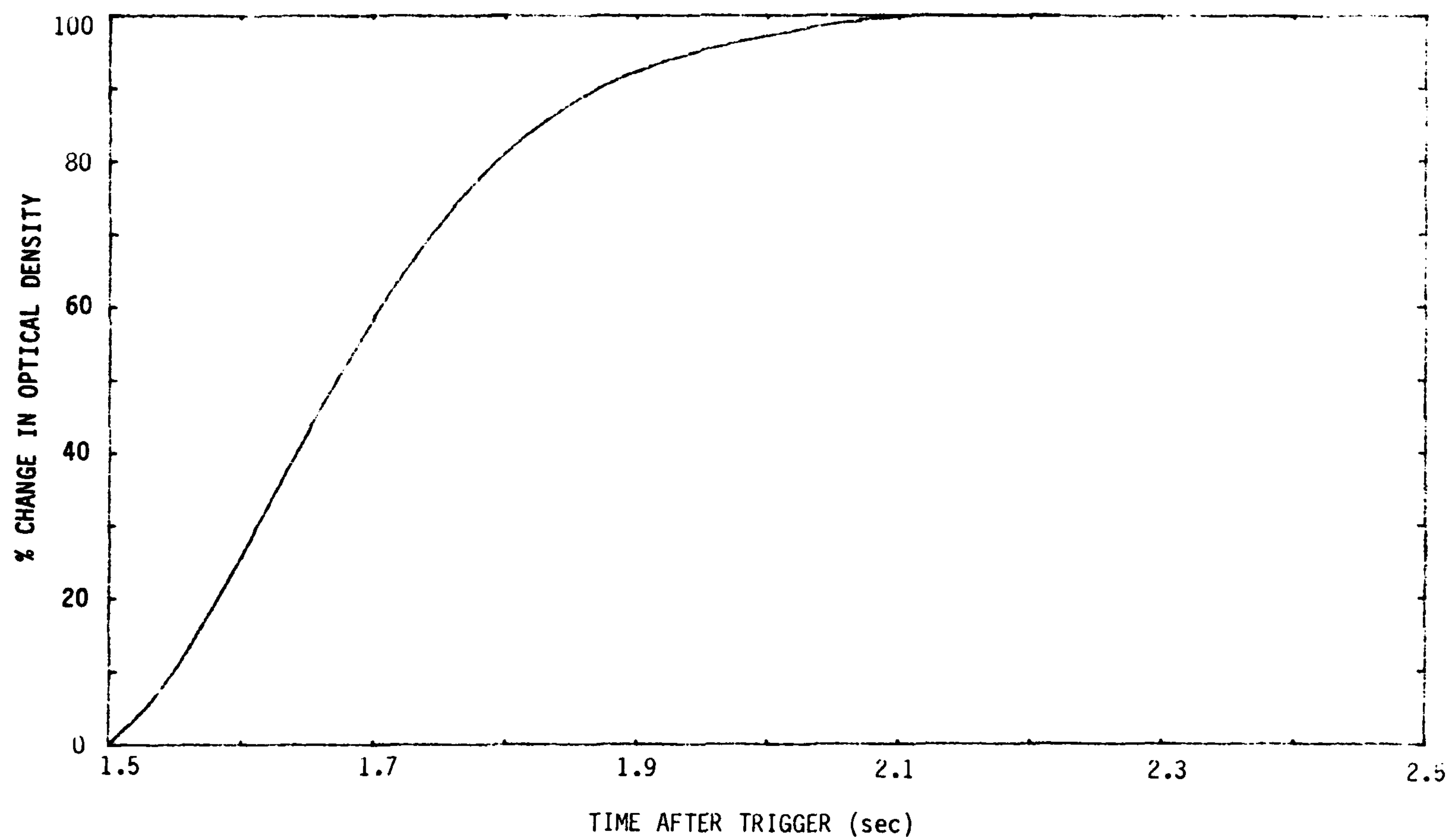

Figure 17. Percent of change in optical density as a function of time after activation for PLZT production goggles in the opening cycle for conditions $\theta_i = \theta_\rho = 0$ and $\theta_i = 18°$, $\theta_\rho = 0$ (assumes no change in ambient light).

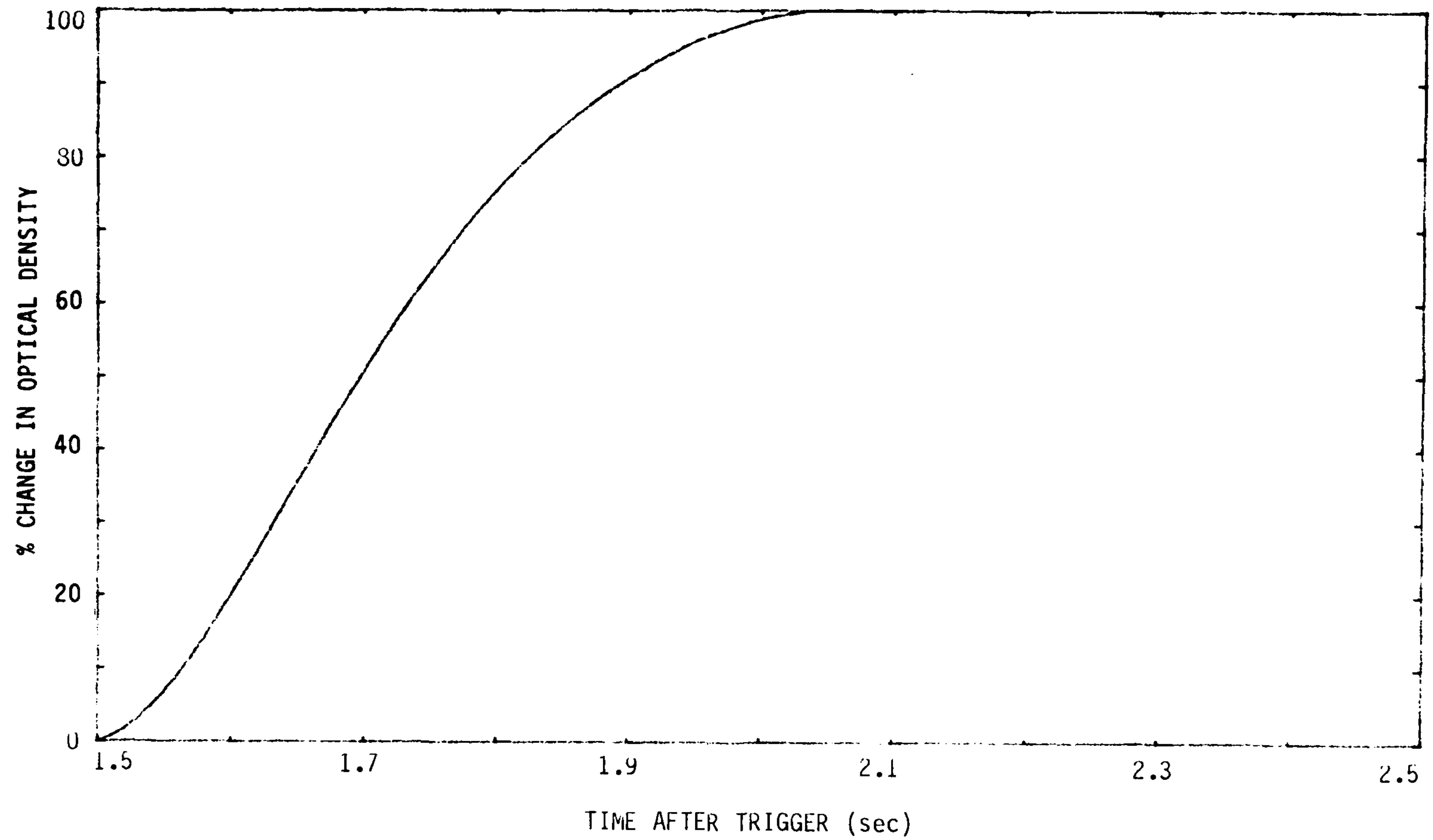

Figure 18. Percent of change in optical density as a function of time after activation for PLZT production goggles in the opening cycle for condition $\theta_i = 37°$, $\theta_p = 43°$ (assumes no change in ambient light).

The data describing the characteristics of the PLZT goggles were used to write a computer program that calculates the spectral transmission of the goggles as a function of time with an assumed activation (trigger) time of 10 μsec. This was incorporated as a subroutine in a modification of the eye-safe-separation-distances program to predict the eye effects resulting from exposure to a nuclear flash under known conditions. This program was then used to predict the possible occurrence of a retinal burn and the flashblindness recovery time for an observer viewing a nuclear flash under the conditions listed in the preceding paragraph at the distances resulting in a thermal load of 10 cal/cm^2. The predictions were made for both day and night (3- and 7-mm pupil diameter, respectively) for the angular conditions of $\theta_i = 18°$, $\theta_\rho = 0$ and $\theta_i = 37°$, $\theta_\rho = 43°$ (i.e., the observer was assumed to be looking straight ahead at the fireball and toward the upper right or upper left at the fireball), for an assumed no-blink condition, and for an assumed blink time of 0.25 second for yields of 100 kt or less and 0.35 second for yields of 1000 kt or more. The results are listed in Tables 1-6 for the prototype goggles and in Tables 7-12 for the production-type goggles.

DISCUSSION

The computer program used to predict the distance from a nuclear detonation at which a thermal load of 10 cal/cm^2 will occur considers only the direct, unscattered radiation between 355 and 1378 nm. Thus, the actual thermal load, considering scattered radiation and the entire thermal spectrum, will be larger than 10 cal/cm^2.

The predicted distance is the surface (sea level) distance between ground zero and a point directly under the observer. This is essentially the slant range when the observer is at the detonation altitude, but is less than the slant range when the observer is at sea level. The thermal loads at ground zero for the 0.1-kt detonation at 1,000 feet (0.3 km) are 3.17 and 3.45 cal/cm^2, respectively, for the 5- and 25-nautical-mile (9.3 and 46.3 km) visibility conditions.

The eye exposures and the resulting eye effects were calculated, as described in Reference 2, with a safety factor of 1. A retinal burn was predicted when the calculated retinal exposure exceeded the burn threshold criteria. Flashblindness recovery time, as used here, is the time required to recover a visual acuity of 20/60 when the visual task has a high contrast (black on white or white on black) and a luminance of 0.07 mL for nighttime and 20 mL for daytime conditions. This corresponds to a pilot's ability to obtain useful information from his primary instruments under normal night and day cockpit conditions (2). In all cases the observer was assumed to be looking directly at the fireball.

Tables 1-12 show that the PLZT goggles, both prototype and production type, provide protection against retinal burns for all exposure conditions tested, even at the worst-case viewing angle ($\theta_i = 37°$, $\theta_\rho = 43°$) and with the observer failing to blink. Retinal burns are predicted for all these exposure conditions if no eye protection is provided. These tables also show that, for all exposure conditions listed, the PLZT production-type goggles provide more protection against flashblindness than do the prototype goggles.

TABLE 1. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 0.1 kt AT 1,000 FT (0.3 km)[a]

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[b]	($\theta_i = 18°$, $\theta_p = 0$)	($\theta_i = 37°$, $\theta_p = 43°$)
ASSUMED NO BLINK				
Visibility: 5 naut. mi				
Day:	0	0.01	1.5	11
	1	0.09	4	11
Night:	0	0.01	19	>77
	1	0.09	46	>77
Visibility: 25 naut. mi				
Day:	0	0.01	1.5	11
	1	0.09	4	11
Night:	0	0.01	19	>77
	1	0.09	47	>77
ASSUMED BLINK TIME: 0.25 sec				
Visibility: 5 naut. mi				
Day:	0	0.01	1.5	11
	1	0.09	4	11
Night:	0	0.01	19	>77
	1	0.09	46	>77
Visibility: 25 naut. mi				
Day:	0	0.01	1.5	11
	1	0.09	4	11
Night:	0	0.01	19	>77
	1	0.09	47	>77

[a] For this detonation yield and altitude, the thermal load at ground zero is less than 10 cal/cm^2.

[b] 1 naut. mi = 1.85 km.

TABLE 2. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 1 kt AT 1,000 FT (0.3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	($\theta_i = 18°$, $\theta_\rho = 0$)	($\theta_i = 37°$, $\theta_\rho = 43°$)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	0.21	2	11
	1	0.27	2	11
Night:	0	0.21	24	>77
	1	0.27	24	>77
			Visibility: 25 naut. mi	
Day:	0	0.23	2	>12
	1	0.29	2	>12
Night:	0	0.23	24	>77
	1	0.29	24	>77
			ASSUMED BLINK TIME: 0.25 sec	
			Visibility: 5 naut. mi	
Day:	0	0.21	2	11
	1	0.27	2	11
Night:	0	0.21	22	>77
	1	0.27	22	>77
			Visibility: 25 naut. mi	
Day:	0	0.23	2	11
	1	0.29	2	11
Night:	0	0.23	23	>77
	1	0.29	23	>77

[a] 1 naut. mi = 1.85 km.

TABLE 3. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 10 kt AT 1,000 FT (0.3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
		ASSUMED NO BLINK		
		Visibility: 5 naut. mi		
Day:	0	0.67	2	>12
	1	0.71	2	>12
Night:	0	0.67	27	>77
	1	0.71	27	>77
		Visibility: 25 naut. mi		
Day:	0	0.79	2.5	>12
	1	0.81	2.5	>12
Night:	0	0.79	29	>77
	1	0.81	29	>77
		ASSUMED BLINK TIME: 0.25 sec		
		Visibility: 5 naut. mi		
Day:	0	0.67	2	11
	1	0.71	2	11
Night:	0	0.67	22	>77
	1	0.71	22	>77
		Visibility: 25 naut. mi		
Day:	0	0.79	2	>12
	1	0.81	2	>12
Night:	0	0.79	24	>77
	1	0.81	25	>77

[a] 1 naut. mi = 1.85 km.

TABLE 4. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 100 kt AT 5000 FT (1.5 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	($\theta_i = 18°$, $\theta_\rho = 0$)	($\theta_i = 37°$, $\theta_\rho = 43°$)
		ASSUMED NO BLINK		
		Visibility: 5 naut. mi		
Day:	0	1.60	2.5	>12
	5	2.01	2.5	>12
Night:	0	1.60	27	>77
	5	2.01	30	>77
		Visibility: 25 naut. mi		
Day:	0	2.10	3	>12
	5	2.34	3	>12
Night:	0	2.10	33	>77
	5	2.34	34	>77
		ASSUMED BLINK TIME: 0.25 sec		
		Visibility: 5 naut. mi		
Day:	0	1.60	1	10
	5	2.01	1	10
Night:	0	1.60	12	>77
	5	2.01	13	>77
		Visibility: 25 naut. mi		
Day:	0	2.10	1	10
	5	2.34	1	11
Night:	0	2.10	15	>77
	5	2.34	15	>77

[a] 1 naut. mi = 1.85 km.

TABLE 5. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 1000 kt AT 5000 FT (1.5 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	3.90	2	>12
	5	4.80	3	>12
Night:	0	3.90	19	>77
	5	4.80	23	>77
			Visibility: 25 naut. mi	
Day:	0	6.00	3	>12
	5	6.48	4	>12
Night:	0	6.00	29	>77
	5	6.48	31	>77
			ASSUMED BLINK TIME: 0.35 sec	
			Visibility: 5 naut. mi	
Day:	0	3.90	<1	3
	5	4.80	<1	3
Night:	0	3.90	4	36
	5	4.80	4	39
			Visibility: 25 naut. mi	
Day:	0	6.00	<1	4
	5	6.48	<1	2.5
Night:	0	6.00	4	45
	5	6.48	5	47

[a] 1 naut. mi = 1.85 km.

TABLE 6. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PROTOTYPE GOGGLES. DETONATION: 10,000 kt AT 10,000 FT (3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

	Observer		Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	8.60	2	>12
	10	13.80	3	>12
Night:	0	8.60	14	>77
	10	13.80	22	>77
			Visibility: 25 naut. mi	
Day:	0	14.90	4	>12
	10	17.90	4	>12
Night:	0	14.90	23	>77
	10	17.90	29	>77
			ASSUMED BLINK TIME: 0.35 sec	
			Visibility: 5 naut. mi	
Day:	0	8.60	<1	2
	10	13.80	<1	1
Night:	0	8.60	<4	21
	10	13.80	<4	14
			Visibility: 25 naut. mi	
Day:	0	14.90	<1	1
	10	17.90	<1	1
Night:	0	14.90	<4	14
	10	17.90	<4	12

[a] 1 naut. mi = 1.85 km.

TABLE 7. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 0.1 kt AT 1000 FT (0.3 km)[a]

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

	Observer: Altitude (kft)	Observer: Surface distance (naut. mi)[b]	Recovery time (sec): (θ_i = 18°, θ_ρ = 0)	Recovery time (sec): (θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	0.01	1	4
	1	0.09	1.5	5
Night:	0	0.01	13	50
	1	0.09	18	53
			Visibility: 25 naut. mi	
Day:	0	0.01	1	5
	1	0.09	1.5	5
Night:	0	0.01	13	51
	1	0.09	18	53
			ASSUMED BLINK TIME: 0.25 sec	
			Visibility: 5 naut. mi	
Day:	0	0.01	1	4
	1	0.09	1.5	5
Night:	0	0.01	13	50
	1	0.09	18	53
			Visibility: 25 naut. mi	
Day:	0	0.01	1	5
	1	0.09	1.5	5
Night:	0	0.01	13	51
	1	0.09	18	53

[a] For this detonation yield and altitude, the thermal load at ground zero is less than 10 cal/cm^2.

[b] 1 naut. mi = 1.85 km.

TABLE 8. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 1 kt AT 1000 FT (0.3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

	Observer		Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
		ASSUMED NO BLINK		
		Visibility: 5 naut. mi		
Day:	0	0.21	1.5	6
	1	0.27	1.5	6
Night:	0	0.21	16	59
	1	0.27	17	59
		Visibility: 25 naut. mi		
Day:	0	0.23	1.5	6
	1	0.29	1.5	6
Night:	0	0.23	17	60
	1	0.29	17	60
		ASSUMED BLINK TIME: 0.25 sec		
		Visibility: 5 naut. mi		
Day:	0	0.21	1.5	5
	1	0.27	1.5	5
Night:	0	0.21	16	57
	1	0.27	16	57
		Visibility: 25 naut. mi		
Day:	0	0.23	1.5	6
	1	0.29	1.5	6
Night:	0	0.23	16	58
	1	0.29	16	58

[a] 1 naut. mi = 1.85 km.

TABLE 9. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 10 kt AT 1000 FT (0.3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

	Observer		Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	0.67	1.5	7
	1	0.71	1.5	7
Night:	0	0.67	19	64
	1	0.71	19	64
			Visibility: 25 naut. mi	
Day:	0	0.79	1.5	7
	1	0.81	1.5	7
Night:	0	0.79	21	67
	1	0.81	21	67
			ASSUMED BLINK TIME: 0.25 sec	
			Visibility: 5 naut. mi	
Day:	0	0.67	1.5	5
	1	0.71	1.5	5
Night:	0	0.67	16	57
	1	0.71	16	57
			Visibility: 25 naut. mi	
Day:	0	0.79	1.5	6
	1	0.81	1.5	6
Night:	0	0.79	17	61
	1	0.81	17	61

[a] 1 naut. mi = 1.85 km.

TABLE 10. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 100 kt AT 5000 FT (1.5 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	($\theta_i = 18°$, $\theta_\rho = 0$)	($\theta_i = 37°$, $\theta_\rho = 43°$)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	1.60	1.5	7
	5	2.01	2.0	8
Night:	0	1.60	19	65
	5	2.01	21	68
			Visibility: 25 naut. mi	
Day:	0	2.10	2	8
	5	2.34	2	8
Night:	0	2.10	24	71
	5	2.34	24	72
			ASSUMED BLINK TIME: 0.25 sec	
			Visibility: 5 naut. mi	
Day:	0	1.60	1	3
	5	2.01	1	3.5
Night:	0	1.60	8	36
	5	2.01	9	40
			Visibility: 25 naut. mi	
Day:	0	2.10	1	4
	5	2.34	1	4
Night:	0	2.10	11	43
	5	2.34	11	45

[a] 1 naut. mi = 1.85 km.

TABLE 11. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 1000 kt AT 5000 FT (1.5 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

	Observer: Altitude (kft)	Observer: Surface distance (naut. mi)[a]	Recovery time (sec): (θ_i = 18°, θ_ρ = 0)	Recovery time (sec): (θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	3.90	1.5	7
	5	4.80	2	8
Night:	0	3.90	13	52
	5	4.80	16	59
			Visibility: 25 naut. mi	
Day:	0	6.00	2.5	9
	5	6.48	2.5	9
Night:	0	6.00	20	67
	5	6.48	22	69
			ASSUMED BLINK TIME: 0.35 sec	
			Visibility: 5 naut. mi	
Day:	0	3.90	<1	1
	5	4.80	<1	1
Night:	0	3.90	<4	9
	5	4.80	<4	10
			Visibility: 25 naut. mi	
Day:	0	6.00	<1	1
	5	6.48	<1	1
Night:	0	6.00	4	12
	5	6.48	4	13

[a] 1 naut. mi = 1.85 km.

TABLE 12. FLASHBLINDNESS RECOVERY TIME; OBSERVER WEARING PLZT PRODUCTION-TYPE GOGGLES. DETONATION: 10,000 kt AT 10,000 FT (3 km)

Retinal Burns: No retinal burns were predicted for this detonation yield and altitude for any of the conditions listed.

Observer			Recovery time (sec)	
	Altitude (kft)	Surface distance (naut. mi)[a]	(θ_i = 18°, θ_ρ = 0)	(θ_i = 37°, θ_ρ = 43°)
			ASSUMED NO BLINK	
			Visibility: 5 naut. mi	
Day:	0	8.60	1.5	6
	10	13.80	2	9
Night:	0	8.60	9	41
	10	13.80	15	57
			Visibility: 25 naut. mi	
Day:	0	14.90	2.5	9
	10	17.90	3	10
Night:	0	14.90	16	60
	10	17.90	20	67
			ASSUMED BLINK TIME: 0.35 sec	
			Visibility: 5 naut. mi	
Day:	0	8.60	<1	<1
	10	13.80	<1	<1
Night:	0	8.60	<4	6
	10	13.80	<4	4
			Visibility: 25 naut. mi	
Day:	0	14.90	<1	<1
	10	17.90	<1	<1
Night:	0	14.90	<4	4
	10	17.90	<4	4

[a] 1 naut. mi = 1.85 km.

Assuming that the production-type TFPD will be provided for aircrew eye protection, we limit the following discussion to a consideration of this type of protective device.

At the worst-case viewing angle and assuming the observer does not blink, the predicted flashblindness recovery time ranges from 40 to 70 seconds for nighttime exposures, but is 10 seconds or less for daytime exposures (Tables 7-12). If the observer is assumed to blink at the time indicated, the recovery times are not significantly changed except for the 1,000- and 10,000-kt detonations. We must remember, however, that only one eye is exposed at the worst-case viewing angle. The other eye is exposed at approximately the straight-ahead viewing angle ($\theta_i = 18°$, $\theta_\rho = 0$). This eye receives less exposure, with consequent shorter recovery time.

In 1966, Hill and Chisum (3) had a group of subjects expose one eye to a bright flash of light while the second eye was protected with an eye patch. They concluded that the exposed eye did not interfere with the unexposed eye in reading the test object which required 20/60 visual acuity. They did not measure the effects on depth perception or other functions requiring binocular vision or test the condition of exposing both eyes, one at a significantly higher level than the other, such as we experience in this situation. We can safely assume, however, that the minimum flashblindness recovery time experienced by the observer cannot be less than that of the eye receiving the lower exposure.

Thus, under the worst-case viewing angle, the observer would experience a recovery time at least as long as that predicted for the straight-ahead viewing angle. At this angle, the predicted flashblindness recovery time for nighttime exposures ranges from 13 to 25 seconds if the observer does not blink. If the observer blinks at the times indicated, the recovery times are not significantly changed except for the 1,000- and 10,000-kt detonations. At the straight-ahead viewing angle the predicted flashblindness recovery time is only 3 seconds or less for all daytime exposures.

The maximum flashblindness recovery time which can safely be tolerated by a pilot is controversial. In 1976 Richey (2) presented evidence to support the use of a 10-second recovery time in general situations. The visual requirements of pilots, however, depend on the mission profile and the position along that profile. Thus, the use of a single number as a maximum safe flashblindness recovery time probably is not justified, except in a general sense.

We repeat, for emphasis, the definition of flashblindness recovery time as used here. It is the time required to recover a visual acuity of 20/60 when the visual task has a high contrast (black on white or white on black) and a luminance of 0.07 mL for nighttime and 20 mL for daytime conditions: corresponding to a pilot's ability to obtain useful information from his primary instruments under normal night and day conditions. Thus, during bright daylight, a pilot's ability to safely control his aircraft will not be significantly affected by a 3-second flashblindness recovery time (maximum predicted for the daytime exposures), but his ability to perform duties requiring a high degree of visual acuity (20/40 or better) will be significantly impaired for a longer period of time if the visual target is in the cockpit. His ability to see details outside the cockpit probably will not be significantly degraded.

At night, however, we predict a maximum recovery time of 18 seconds if the observer blinks at the assumed time. A pilot's ability to control his aircraft will be degraded, and his ability to perform duties requiring a high degree of visual acuity will be seriously impaired for longer recovery times.

In principle, nighttime flashblindness protection can be improved by decreasing the closing time, increasing the closed-state spectral density, increasing the luminance of the visual task to be performed, or by a combination of any two or all three of these. We believe efforts to improve the closure time and closed-state spectral density of existing devices have reached the point of diminishing returns; i.e., a major effort would be required to produce a small improvement which would not significantly affect the protective capability of the devices. An increase in the luminance of the aircraft instruments after a nuclear detonation, however, would not be difficult to achieve, and an increase in the luminance from 0.07 mL to 7 mL will reduce the time required to read the instruments by a factor of 5 (from 20 sec to 4 sec in the present case). As the pilot recovers from the effects of the flashblindness, he can manually reduce the luminance to the desired level. This may increase the time required to regain his vision outside the cockpit, but will enable him to see his instruments in a much shorter period of time.

CONCLUSIONS AND RECOMMENDATIONS

The Air Force production-type TFPD furnished to USAFSAM for testing and evaluation will provide adequate eye protection, during both daytime and nighttime exposures, to prevent retinal burns from atmospheric nuclear detonations of 0.1 to 10,000 kt at distances where the thermal load does not exceed 10 cal/cm^2. This device will also provide sufficient protection against flashblindness during daylight hours to prevent more than a few seconds degradation in the pilot's performance. Interference with the mission should be minimal unless the exposure occurs during a very critical phase of the mission profile demanding continuous high visual acuity.

At night, however, the PLZT goggles will not prevent flashblindness recovery times of about 20 seconds for some exposure conditions, particularly the lower yield detonations. The pilot's ability to see his instruments will be significantly impaired during this period of time.

The decrease in optical density of the TFPD at large values of θ_i and θ_p, the worst-case viewing angle, is not of major concern since only one eye is exposed at this worst-case angle, and this eye is protected from permanent damage while the protection provided to the opposite eye is not degraded. In addition, the probability of exposure at this extreme viewing angle is quite small.

We recommend that, at night, consideration be given to automatically increasing the instrument luminance when a nuclear flash is encountered. The luminance should be increased to at least 7 mL but need not exceed 100 mL. A manual control should be provided to enable the pilot to reduce the luminance as he recovers from the flashblindness.

REFERENCES

1. Cutchen, J. T. Sandia Laboratories, Albuquerque, N. Mex. Personal communication, 1978.

2. Richey, E. O. Predicting eye safe separation distances from nuclear detonations. SAM-TR-76-38, Dec 1976.

3. Hill, J. H., and G. T. Chisum. Flashblindness protection: The eye patch. Aerosp Med 37:813 (1966).